Supplementary material

Distance-dependent pattern blending can camouflage salient aposematic signals

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1. Identification accuracy

Visual modelling from calibrated photographs (see main manuscript) showed that human and avian vision are broadly comparable for the stimuli and environments used for these experiments (Figure S1), and that similar distance dependent effects were seen in both visual systems (Figure S2). We were therefore able to use human participants as surrogate predators in a detection experiment.

In order to assess the detectability of striped patterns at different distances, we asked human participants to identify whether ‘caterpillars’ were striped or plain when shown the stimuli at three different viewing distances.

Ten participants (five male and five female) were shown the yellow-and-black stimuli (Y_P, B_P, Y_A, Y_T, Y_M, and Y_L) in June 2013, and in a separate experiment nine different participants (five male and four female) were shown the green-and-black stimuli (G_P, B_P, G_A, G_T, G_M, and G_L) in June 2015. The experiments were run outside under natural daylight conditions. All participants had normal or corrected to normal vision and gave their informed consent in line with the Declaration of Helsinki.

Participants were familiarised with the treatment designs at arm’s length, and then were presented with the caterpillars against a white background at 6 m, 10 m, and 15 m. For each distance five of each treatment (n = 90 per colour) were presented in a random sequence, and each participant conducted the three distances in a random order. Each experiment was analysed with a binomial generalized linear mixed effects model from package *lme4* [S1] in R 3.1.3 (The R Foundation for Statistical Computing, Vienna, Austria). Subject was included as a random factor, and pairwise tests used the False Discovery Rate from package *multcomp* [S2], to achieve a suitable balance between Type I and II errors. Data are available in Dryad [S3].

2. Results

a) Yellow-and-black

At 6 m all yellow-and-black caterpillars were correctly identified so no statistical tests could be performed. Data were, therefore, split by distance for subsequent analysis (Figure S3). At 10 m there was a significant effect of treatment ($\chi^2 = 14.33$, d.f. = 5, p = 0.014), but no significant pairwise tests ($z < 1.52$, $p > 0.566$).

At 15 m there was a significant effect of treatment ($\chi^2 = 101.69$, d.f. = 5, $p < 0.001$), and pairwise tests show that identification accuracy was significantly lower for the highest spatial frequency (thinnest) stripes when compared to lower spatial frequency (medium and largest) stripes ($Y_T – Y_M$: z = -3.52, p = 0.004; $Y_T – Y_L$: z = -4.35, $p < 0.001$), and for the medium stripes compared to the lowest spatial frequency stripes ($Y_M – Y_L$: z = -2.28, p = 0.042). There was no significant difference between plain yellow and plain black treatments (Y_P – B_P: $z < 0.001$, $p > 0.999$), and no difference between the plain yellow or plain black and the lowest spatial frequency stripes ($Y_L – Y_P$: z = -0.58, p = 0.989; $Y_L – B_P$: z = -0.58, p = 0.989). The medium and thinnest spatial frequency stripes were identified with significantly less accuracy than the plain yellow and plain black (Y_T-Y_P: z = -4.85, $p < 0.001$; Y_T-B_P: z = -4.85, $p < 0.001$; Y_M-Y_P: z = -2.82, p = 0.040; Y_M-B_P: z = -2.82, p = 0.040). All of the plain average colour (Y_A) caterpillars were correctly identified so pairwise comparisons with this treatment were not possible.

b) Green-and-black: identification accuracy

For the green-and-black striped caterpillars there was a significant interaction between treatment and viewing distance ($\chi^2 = 50.62$, d.f. = 5, $p < 0.001$; Figure S4). At 6 m there was a significant effect of treatment ($\chi^2 = 41.33$, d.f. = 5, $p < 0.001$), and identification accuracy was significantly lower for the highest spatial frequency stripes when compared to lower spatial frequency stripes ($G_T - G_M$: $z = -2.96$, $p = 0.033$; $G_T - G_L$: $z = -3.71$, $p = 0.003$) and the plain treatments ($G_T - G_P$: $z = -3.58$, $p = 0.004$; $G_T - G_A$: $z = -3.49$, $p = 0.006$; $G_T - B_P$: $z = -3.74$, $p = 0.002$). There was no significant difference between the medium and low spatial frequency stripes (G_M-G_L: $z = -1.34$, $p = 0.750$). Furthermore, there was no significant difference between the plain treatments ($z < 1.30$, $p > 0.770$), or between the medium and low spatial frequency stripes and the plain treatments ($z < 1.96$, $p > 0.347$).

At 10 m there was a significant effect of treatment ($\chi^2 = 247.70$, d.f. = 5, $p < 0.001$). There was no significant difference between striped patterns ($G_T - G_M$: $z = -1.30$, $p = 0.769$; $G_T - G_L$: $z = -2.67$, $p = 0.075$; $G_M - G_L$: $z = -2.16$, $p = 0.238$), but striped patterns were detected significantly less accurately than plain patterns ($G_T - G_A$: $z = -5.33$, $p < 0.001$; $G_T - B_P$: $z = -5.33$, $p < 0.001$; $G_T - G_P$: $z = -5.50$, $p < 0.001$; $G_M - G_A$: $z = -5.36$, $p < 0.001$; $G_M - B_P$: $z = -5.36$, $p < 0.001$; $G_M - G_P$-: $z = -5.88$, $p < 0.001$; $G_L - G_A$: $z = -4.54$, $p < 0.001$; $G_L - B_P$: $z = -4.54$, $p < 0.001$; $G_L - G_P$: $z = -5.05$, $p < 0.001$). There was no significant difference between plain treatments ($z < 0.58$, $p > 0.991$).

Similarly, at 15 m there was a significant effect of treatment ($\chi^2 = 261.21$, d.f. = 5, $p < 0.001$). There was no significant difference between striped treatments ($G_T - G_M$: $z = -0.58$, $p = 0.992$; $G_T - G_L$: $z = -1.92$, $p = 0.378$; $G_M - G_L$: $z = -1.65$, $p = 0.548$), but striped patterns were identified with significantly less accuracy than plain patterns ($G_T - G_A$: $z = -5.29$, $p < 0.001$; $G_T - B_P$: $z = -5.51$, $p < 0.001$; $G_T - G_P$: $z = -5.47$, $p < 0.001$; $G_M - G_A$: $z = -5.51$, $p < 0.001$; $G_M - B_P$: $z = -6.00$, $p < 0.001$; $G_M - G_P$: $z = 6.08$, $p < 0.001$; $G_L - G_A$: $z = -5.02$, $p < 0.001$; $G_L - B_P$: $z = -5.72$, $p < 0.001$; $G_L - G_P$-: $z = -5.97$, $p < 0.001$). There was no significant difference between plain treatments ($z < 0.98$, $p > 0.921$).

3. Conclusion

We found that for both yellow-and-black and green-and-black stripes, increasing spatial frequency (thinner stripes) decreased the distance at which human observers could resolve the stripes. For both yellow-and-black and green-and-black caterpillars, accuracy was high at 6 m but was significantly less accurate at 10 m and 15 m, with an increasing number of mistakes for thinner stripes at greater distances. These data support the conclusion that stripe spatial frequency significantly affects the distance from which cryptic and aposematic stripes can be identified by potential predators.

Supplementary references

S1 Bates D, Maechler M, Bolker B, Walker S. 2015 Fitting linear mixed-effects models using lme4. *J. Stat. Softw.* **67**, 1-48. (doi:10.18637/jss.v067.i01).

S2. Hothorn T, Bretz F, Westfall P. 2008 Simultaneous inference in general parametric models. *Biom. J.* **50**, 346-363. (doi:10.1002/bimj.200810425).

S3. Barnett JB, Cuthill IC, Scott-Samuel NE. 2017 Data from: Distance-dependent pattern blending can camouflage salient aposematic signals. Dryad Digital Repository. (doi:10.5061/dryad.2h6nf).

Figures

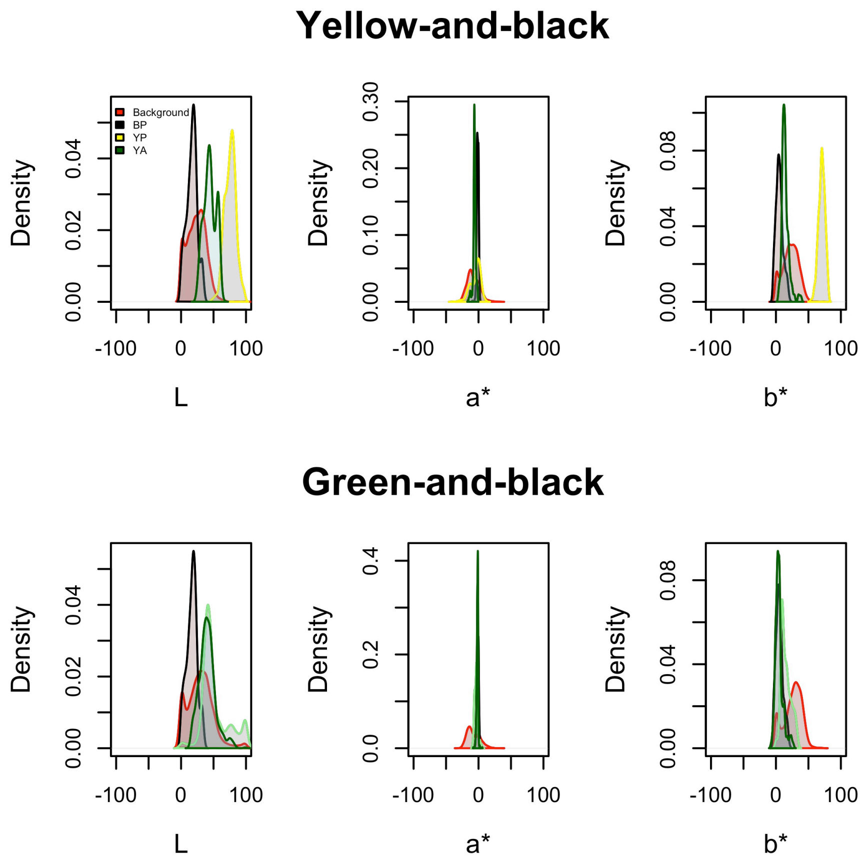

Figure S1. Caterpillar and background colours as viewed by the human visual model (L*a*b*). All colours are represented in the background (red), apart from Y_P (yellow) which is distinct from the background in luminance (L) and the b* channel.

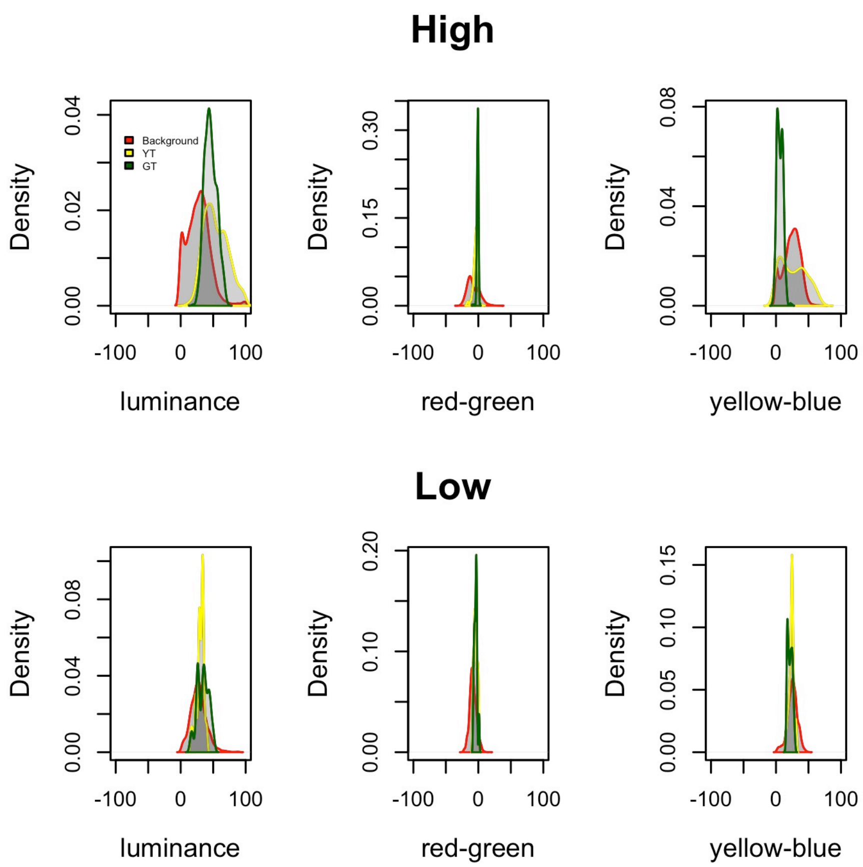

Figure S2. The bramble background (red) and high spatial frequency (thinnest) striped caterpillar treatments (yellow – Y_T; green – G_T) viewed by the human L*a*b* visual model at high, (top), and low, (bottom), spatial resolutions. Pattern blending at the low spatial resolution forms colours which are a better match to the background for both Y_T and G_T stimuli.

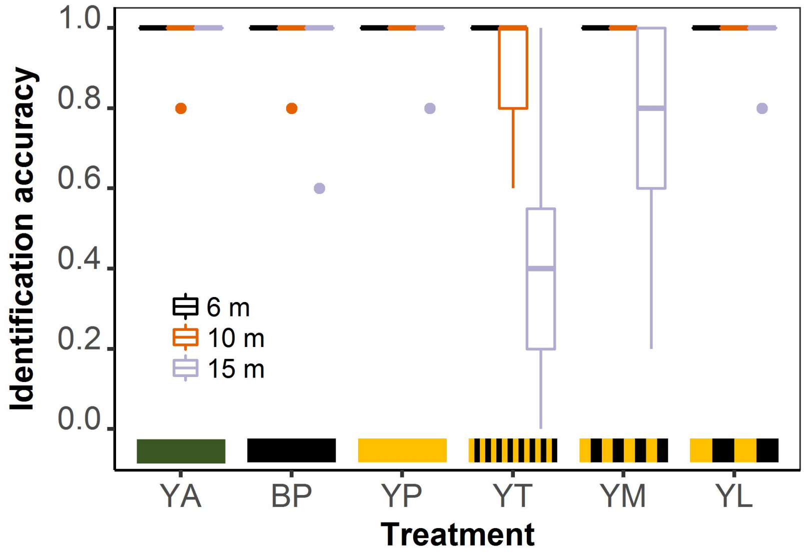

Figure S3. Proportion of yellow-and-black caterpillar patterns correctly identified from 6 m, 10 m, and 15 m (raw data per subject). As distance increased stripe identification accuracy decreased with the rate of decline greatest for the thinner stripes.

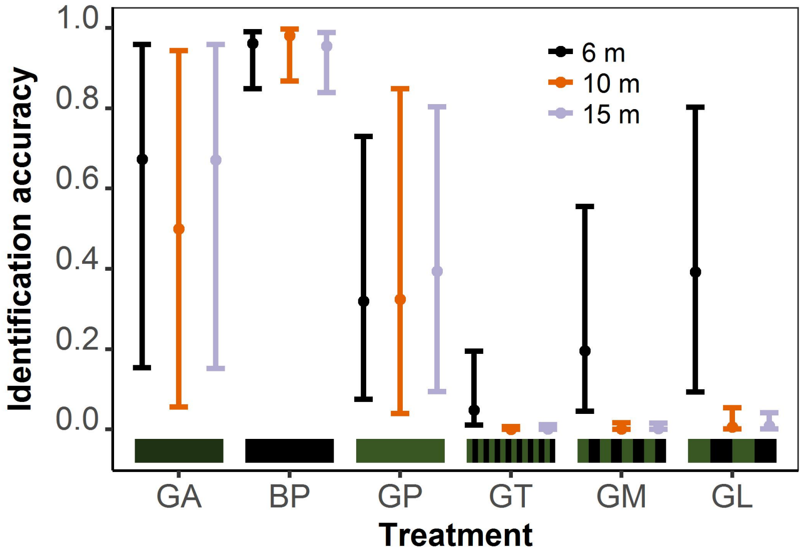

Figure S4. Relative accuracy of caterpillar identification at 6 m, 10 m, and 15 m (mean accuracy with 95% CI from the model). Stripe identification accuracy declines as distance increases, with the accuracy lowest for the thinnest stripes (G_T).